PB89-119440

Fate of Pollutants (Journal Version)

(U.S.) Environmental Research Lab.
Gulf Breeze, FL

1988

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before compl		
1. REPORT NO. EPA/600/J-88/171	2.	PB89-119440
4. TITLE AND SUBTITLE Fate of Pollutants (Journal Version)		5. REPORT DATE 1988 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) P. H. Pritchard		8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS Same as (12)		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Research Laboratory - Gulf Breeze, FL Office of Research and Development U.S. Environmental Protection Agency Gulf Breeze, FL 32561		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/4

15. SUPPLEMENTARY NOTES

J. Water Pollut. Control Fed. 60(6):983-994. 1988.

16. ABSTRACT

Published literature on the environmental fate of pollutants published during 1987 are reviewed. Short excerpts are presented from each reference covering such areas as photolysis, biodegradation, hydrolosis, sorption, and volatility for pollutants including pesticides, hydrocarbons, heavy metals, polynuclear hydrocarbons, and other toxic organic chemicals.

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	13
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA/600/J-88/171
JOURNAL ARTICLE

Fate of pollutants

P. H. Pritchard

CHLORINATED XENOBIOTIC CHEMICALS

A field study on the distribution in water and sediment of chlorophenolic compounds from a bleaching effluent revealed

June 1988
JWI[illegible](9)(6):993-994

that octanol-water partition coefficients corrected for pH were very important in determining the fate of these phenolics.[1] Biodegradation also strongly influenced their fate, especially in sediments containing large amounts of organic carbon. The fate of chlorinated phenolics in bleached kraft mill effluent from a Finnish pulp mill was assessed by aging the effluent under laboratory conditions using nutrient solutions and three types of lake water.[2] The order of decay for the phenolics was chlorocatechols, followed by the chlorophenols and finally the chloroguiacols. Concentrations of 2,3,4,6-tetrachlorophenol and pentachlorophenol (PCP) in a Danish fjord were high, presumably because of industrial activities.[3] The distribution of the concentrations suggested a general nonpoint source rather than a dump site and may have been partly responsible for the pollution in the fjord. Hwang *et al.*[4] showed that photolysis is the primary transformation process affecting the fate of 2,4-dichlorophenol, 2,4,5-trichlorophenol and PCP in estuarine water, whereas biodegradation was the main fate process affecting phenol and 4-chlorophenol. Both photolysis and biodegradation were considerably reduced in the winter. The chronic flux of PCP into a wastewater-estuarine aquaculture system resulted in the elevated concentrations in water, sediment and shrimp.[5] Once the input of PCP was eliminated, no persistence was observed, suggesting that dilution and microbial degradation in sediment were responsible for the elimination of the chemical.

Krijgsheld and van der Gen[6-8] have thoroughly reviewed the literature regarding the impact and persistence of several types of organochlorines in aquatic environments. The chemicals reviewed are mono- and dichlorophenols, allylchloride, dichloropropene and epichlorohydrin. Estimates of average half life as well as possible pathways of degradation are given. A single issue of the journal *Chemosphere* has been dedicated to current research on all aspects of chlorinated dioxins and related compounds.[9]

The presence of dissolved humic substances in water enhanced apparent aqueous solubility of three chlorodioxins.[10] The change was consistent with an effect from van der Waals forces and, although the effect was weak, it can be expected to play a significant role in the environmental fate of chlorodioxins. Photolysis studies of dibenzo-*p*-dioxin in solvent at 253 nm showed that 2-hydroxybenzoate was the principal product following a photochemical cascade through a series of hydroxylations.[11] The volatility and photolytic decay of dioxin have also been characterized.[12-13] Transformation of dioxin to less chlorinated congeners was rapid under photolytic conditions in water and air.

Marple *et al.*,[14-15] using a procedure of subliming 50 to 100 molecular layers of radiolabeled dioxin on the collector glass of a sublimator and then measuring equilibrium concentrations with water, showed the solubility of dioxin to be approximately 12 to 19 parts per trillion, a value close to that predicted from octanol-water partition experiments.

Wu and Aschwend have presented experimental evidence consistent with the theory that the sorption kinetics of organic pollutants to sediments is controlled by intra-particle diffusion.[16] Their results demonstrate that bigger aggregates have lower uptake rates, that compounds with higher octanol-water partition coefficients show slower sorption and that desorption rates are consistent with a reversible diffusive exchange mechanism. A novel conceptual model for sediment mass dependent adsorption of organics was presented[17] and is consistent with the particle induced desorption hypothesis of DiToro. The sorption is considered as a loose surface accumulation of the chemical that can be disrupted by collisions between particles; when a significant fraction of the sorbate is sorbed, collision-induced desorption becomes important and limits the sorbed concentration to approximately an equal amount to that in solution.

de Bont *et al.*[18] have isolated several bacteria that will grow on 1,3-dichlorobenzene as a sole carbon and energy source. Their studies revealed a straight forward hydroxylation and subsequent cleavage of the aromatic ring with the production of a dichloromuconic acid product. Alpha-hexachlorocyclohexane degraded to chlorinated phenols and benzenes in soil slurries under both aerobic and anaerobic conditions; the latter required a 30-day acclimation period.[19] The absence of any degradation of the beta isomer under any redox conditions suggested a spatial chloride arrangement effect on its susceptibility to biological attack. To determine the biodegradability of β-aryl-bound chlorinated phenolic residues, the veratrylglycerol β-aryl ether of pentachlorophenol was synthesized and subjected to degradation by *Corynebacterium equi* and *Phanerochaete chrysosporium* and to the riboflavin/light system for producing oxygen radicals.[20] The photochemical system and the degradation by *P. chrysosporium* resulted in the release of pentachlorophenol and a dimethoxy benzaldehyde. The bacterium did not degrade the chemical. There was no sterospecificity with those systems that did degrade the aryl ether.[21]

Analysis of the difference spectroscopy of humic acids mixed with chlorinated benzoquinones in aqueous solution suggest that binding sites for the organic molecules exists on the dissolved humic materials.[22] A charge-transfer or electron donor-acceptor mechanism seemed responsible for the interaction between sites on the humic acids and organic molecules. Studies on the water solubility enhancements of several chlorinated chemicals by dissolved organic matter indicates that the enhancement effect varies with the molecular composition of the aquatic humic materials.[23] Commercially available humic acids gave enhancements that were 4 to 20 times greater than natural humics through aquatic sites.

The degradation of two groups of important groundwater contaminants, alkylbenzenes and halogenated aliphatic hydrocarbons, was studied in a methanogenic aquifer material.[24] The alkylbenzenes (toluene, benzene, ethylbenzene and *O*-xylene) all disappeared, after considerable lag (except for toluene) and were faster in active than in sterile systems. Studies with radiolabeled toluene verified the existence of biodegradation. All of the aliphatic hydrocarbons disappeared and vinyl chloride was produced from di- and trichloroethylene. The reductive dehalogenation of a variety of halogenated aromatic chemicals did not occur in sulfate reducing aquifer material but did occur in similar methanogenic material.[25] However, once sulfate was consumed by microbiological processes, dehalogenation commenced. Differences were noted in the types of chlorophenols, chlorobenzoates and phenoxyacetic acid herbicides that were attached by methanogenic consortia in wastewater, pond sediment, and aquifer material. Reactivities of several bromoalkanes in water showed the order of decreasing half lives to be 1,2-dibromoethane, 1,2-dibromopropane, 1-bromo-3-phenylpropane, 1,3-dibromopropane and 1-bromoheptane.[26] Hydrogen bromide, vinyl bromide, bromopropenes and alcohols were released as products.

Vogel *et al.*[27] have critically reviewed the biotic and abiotic transformations of halogenated compounds. Trichloroethane

was biotransformed by reductive dehalogenation to 1,1-dichloroethane, chloroethane, and vinyl chloride under methanogenic conditions.[28] These products are then mineralized to CO_2 under similar conditions. The degradation of trichloroethylene in microcosms simulating groundwater environments was described by Michaelis-Menten kinetics.[29] With soils of high organic matter, the nonlinear form of the equation gave the best fit to the data whereas with low organic content soils a linear fit was the best. Degradation rates were a function of both microbial biomass and organic matter content. Cooper *et al.*[30] have studied the abiotic decay of 1,1,2,2-tetrachoroethane to 1,1,2-trichloroethene in aqueous phosphate buffers and found a definite pH dependence; neutral pHs gave half lives of 102 days and high pHs gave half lives of 1.02 days. Biodegradation of pentachloroethene was maximized using a known pure culture of a dehalogenating anaerobe and its methane-producing consortium.[31] Slower rates of dehalogenation occurred with other pure cultures of anaerobic methanotrophs.

Laboratory-derived correlations between PCB partition coefficients and properties of specific environmental phases did not accurately predict the trends in speciation observed in Lake Superior.[32] The data, however, were explained by the presence of contaminant-associating colloidal matter, a factor which could have a substantial impact in controlling the aquatic behavior of chlorinated hydrocarbons. The relationship between the calculated total molecular surface area (TSA) and the octanol water partition coefficient (K_{ow}) was examined for 32 highly hydrophobic aromatic compounds, including PCBs, polybrominated biphenyls, polychlorinated dioxins and polychlorinated furans.[33] A correlative method was developed for estimating the K_{ow} values from the TSA for chemicals from 3.89 to 8.58 in log K_{ow}. Villeneuve and Cattini[34] have shown that concentrations of a variety of chlorinated hydrocarbons in rainwater over the Mediterranean Sea are similar to other areas in the world and are correlated with the movements of air masses. However, dry deposition of these chemicals appears to be the most important input source for the Western Basin of the Mediterranean Sea. Concentrations of organochlorines have been measured in sediment samples from the Mississippi River and DDE was in highest concentration in most samples.[35] Bush *et al.*[36] have studied the distribution of 74 PCB congeners in sediment cores from the Hudson River and conclude that although volatility undoubtedly affected congener distribution in intertidal areas, precipitation and scavenging from the water column may be responsible for hot spots rather than anaerobic microbial dechlorination. Active dissolution into the water column was a minor source of PCB removal from sediments. DDT and PCBs have been monitored in River Po sediments and PCB concentrations have been reported from other riverine sediments.[37–41] Monitoring studies have revealed metabolites of polychlorinated biphenyls in lake sediment in Switzerland;[42] chlorinated hydrocarbons in sediments in California;[43] haloethanes in seawater as a result of chlorination;[44] chloroform; tetrachloroethylene and bromoform in a Swedish fjord;[45] and DDT, heptachlor, aldrin, dieldrin, and endrin in seawater.[46] Jaffe and Hites[47] have used gas chromatographic, methane-enhanced, negative ion mass spectrometry to analyze for a group of fluorinated aromatic chemicals in Lake Ontario sediments. The results showed that chemicals leaking from a hazardous waste site were rapidly transported across the entire lake and accumulated in three sediment basins and in fish. The flame retardant, decabromobiphenyl ether, has been detected at about 0.2 μg/g in river sediments in Japan.[48] Preliminary evidence suggested that the chemical is susceptible to photolysis, producing less brominated compounds. Hexabromobenzene, another type of flame retardant, was found in sediments of Tokyo Harbor.[49] The breakdown products tri-, tetra-, and pentabromobenzene were also found in the sediments. The photolysis of chloroacetones in water has also been reported.[50]

NONCHLORINATED XENOBIOTIC CHEMICALS

Results from a recent symposium on the sources and fates of aquatic pollutants have been published.[51] The influence of phenol and cyanide on the biodegradation of glucose in stream water, a situation possibly found in industrially-impacted streams, suggested that degradation rates were related to substrate concentration and that the more readily degradable substrates adversely affected degradation of the other substrates.[52] Because removal rates of phenol and cyanide were nonlinear with respect to chemical concentration, the author speculates that other complex chemicals might interfere with degradation. The mineralization kinetics of high concentrations of p-nitrophenol were stimulated by the presence of glucose apparently because of increased growth rates.[53] Phenol inhibited p-nitrophenol mineralization and changed the substrate depletion kinetics to give misleading interpretations if growth dynamics were not considered. A photogenerated dissolved organic matter-derived transient oxidant, probably organic peroxy radical, exhibited high reactivity toward alkylphenols.[54] Reactivity of alkylphenols toward the transient oxidant increased with increasing ring substitution by methyl groups but decreased with increasing size of the alkyl group for 4-alkylphenols. Borlakoglv and Kickuthe[55] have shown that phenolic compounds resulting from the decay of plant material can become chlorinated through the standard chlorination of drinking water. The resulting chlorinated phenols could represent potential toxicants. Bossert and Young[56] have shown the mechanism by which *p*-cresol is degraded under anaerobic, denitrifying environments to be the oxidation of the methyl group producing *p*-hydroxybenzoate. This anaerobic oxidation was suggested as the principal means of degrading aromatic compounds in anoxic environments. Studies on aerobic biodegradation processes in natural aquifer material showed that metabolic abilities and nutrient requirements of groundwater microorganisms varied substantially in an aquifer.[57] Mineralization of ethylene dibromide, *p*-nitrophenol, phenol, and toluene was stimulated by the addition of inorganic nutrients in some samples but not in others. The addition of readily degradable organic material slowed degradation of the test chemicals. Using the new technique of solid-state ^{13}C nuclear magnetic resonance spectroscopy, it has been shown that the metabolism of the natural substrate, acetate, by a *Pseudomonas* isolate from soil, was significantly altered by simultaneous metabolism of the pollutant chemical, phenol.[58] The relative concentration of the two substrates influenced their rate and manner of metabolism. The spectroscopic technique allows biodegradation processes to be examined without extraction, fractionation, or isolation of cellular components. With a silica/alumina column fractionation procedure and GC/MS, the nitrogen-containing aromatic compounds present in creosote and marine sediments from a creosote-contaminated harbor were analyzed.[59]

Biodegradation tests with poorly-soluble compounds performed best when the substrate was homogenized, the reaction

degradation, that is, initial ring hydroxylation to cyclohexanol and eventual oxidation and ring opening to give adipic acid, was similar to those reported for two other known cyclohexane degraders.[107] Wakeman *et al.*[108] followed the fate of radiolabeled octadecane and decane in a large physical model of Narrangansett Bay and found that during the summer months biodegradation accounted for 80 and 95% of the removal of the hydrocarbons, respectively. Volatilization and sedimentation, in contrast to other similar studies, were minor factors in the overall fate.

Latimer *et al.*[109] have shown that detention basins for the treatment of pollutants generated by land runoff is an effective way to reduce pollutant impact on receiving waters. Treatment efficiencies for hydrocarbons and polycyclic aromatic hydrocarbons (PAHs) in the detention basins were considerably better than combined sanitary/storm municipal treatment plants. High concentrations of PAHs from anthropogenic inputs have been detected and characterized in 14 stations in the Saquenay Fjord, Canada.[110] Total PAHs decreased with down stream distance from aluminum smelting plants; they were generally at higher concentrations in the deeper layers of sediment. The hydrocarbons benzo[b]fluoranthrene, benzo[a]pyrene, [1,2,3-cd]pyrene and benzo[ah]-anthracene were highest in concentration. Shiaris and Jamband-Sweet[111] have provided a comprehensive survey of PAHs in Boston Harbor, Mass. Total PAH concentrations, which were from 0.5 to 700 μg/g dry weight of sediment, were highest in areas with proximity to wastewater outfalls and urban centers. Observed distributions of PAHs in Gulf of Maine sediments supported the conclusion that the principal transport mechanism for these hydrocarbons was through the atmosphere with localized augmentation by sediment resuspension.[112] A PAH-containing extract from Black River sediments was characterized for the types of PAHs present and their genotoxic activities, as determined by unscheduled DNA synthesis and Ames test mutagenicity.[113] Significant mutagenicity was associated with fractions containing 4 to 6 aromatic rings, with the majority of the activity found with the 5-ring compounds. Unscheduled DNA synthesis was associated with the 4-ring fractions containing the alkylated PAHs. Readman *et al.*[114] described an analytical protocol to quantitatively determine the amount of wastewater, oil and PAHs present in natural water samples. The principal analytical tool was flame ionization gas chromatography. Coprostanol was used as the marker for wastewater pollution.

Using reverse-phase chromatography with a polar alkylcyano medium (a sorbent phase similar to sediment organic matter), partition coefficients for a variety of alkyl benzenes and PAHs were compared with octanol-water and sediment-water partition coefficients.[115] Good correlation was obtained in all cases but the alkylcyano capacity factors better reflected sediment capacity factors than did octanol or octadecylsilane phases. A method for determining equilibrium constants for PAHs has been proposed using fluorescence quenching caused by the association of PAHs with humic acid material.[116] The results obtained with this method reasonably correlated with values determined from reverse-phase liquid chromatography. Partitioning of PAHs to organic matter in Lake Michigan was more a function of the source of the organic matter rather than the solubility of the PAHs.[117] Partitioning values ranged over several orders of magnitude in different natural waters, but for many water samples, partitioning was directly related to solubility.

A study of the effects of different types and different concentrations of suspended sediment on the biotransformation rate of acenaphthene, showed that at a high sediment concentration (600 mg/L) a significant increase in degradation rate occurred.[118] Degradation rate was directly proportional to sediment concentration but slower degradation rates were associated with the sediment of higher organic content. Dimethyl benzanthracene was rapidly degraded in the seawater of large outdoor microcosms probably by combination of biodegradation and photolysis.[119] Unaccountable losses of radioactivity were attributed to the formation of nonextractable bound residues in sediments. The photoreaction of pyrene in aqueous nitrite solution was shown to produce 1-nitropyrene, a compound that gives strong mutagenicity toward *S. typhimurium* TA 98.[120]

PESTICIDES

Alachlor, an acetonilide herbicide, and its metabolites resisted complete mineralization by natural bacterial communities even in samples preexposed to the pesticide. However, partial metabolism to organic products was observed in soils[121] and in lake water and wastewater.[122] Propachlor was readily mineralized and degradation produced N-isopropylaniline as a product. Francis[123] has shown in terrestrial-aquatic laboratory model ecosystems that alachlor, atrazine, linuron, and orysalin were not persistent and should therefore pose no environmental risk. Little interaction in environmental fate was observed when the herbicides were paired individually with paraquat. Aldicarb, aldicarb sulfoxide, and aldicarb sulphone were found in Caloosahatchee River, Fla.[124]

Concentrations of diazinon, carbofuran, azinphosmethyl, and methyl parathion were highest in the water of a lake in Greece during summer, indicating significant agricultural runoff.[125] Biodegradation studies on the pesticide methyl parathion in estuarine waters show biodegradation occurred only in the presence of sediment and a very simplified geographic grouping of the degradation rates was observed.[126] These results suggest that predictions of the fate of a chemical in sediments in a specified geographic area may be approachable.

Comparative studies on the photolysis of two carbamate pesticides, carbendazine and benlate, revealed the production of the same products in methanol.[127] The repeated addition of α-naphthol or carbofuran phenol, hydrolysis products of carbaryl and carbofuran respectively, to flooded soils resulted in faster disappearance of the parent pesticide.[128] Enhanced disappearance, however, led to the accumulation of large amounts of hydrolysis products that were not further degraded. The fate and toxicity of carbaryl in systems containing a synthetic community designed to model a food chain of either excreta to algae to snail or midge and plankton to mosquito larvae to fish, was shown to be directly related to pH and biodegradation.[129] Although the pesticide persisted longest at high pH, its biotic decay was sufficient to prevent toxicity to the food chain. The persistence of methyl parathion in the water, sediment and plants of a carp pond was longest in plants and shortest in the water.[130] However, degradation was observed in all components including the carp. Using a synthetic community of algae, snails, fish, mosquito larvae, and EPA reference water buffered to pH 8.3 and 6.7, the persistence of radiolabeled fenitrothion was shown to be less at the lower pH because of hydrolytic processes.[131] The uptake of

radioactivity by the organisms in the community was higher at the lower pH, suggesting the uptake of degradation products. Similar studies with aldicarb showed that pH had a minimal effect on environmental fate of the herbicide.[132] However, the formation of the aldicarb sulfoxide, a more stable compound of equal toxicity, was affected by pH of 7.0 or higher.

Camaphos, a phosphorothiolate insecticide, was readily removed from the wastewater of livestock dipping operations through a combination of bacterial degradation and fragmentation by UV-ozonation.[133] The biodegradation cleaved the phosphorothioate linkage and the UV-ozonation treatment a fragmented the aromatic ring that was normally resistant to microbial attack. Endothal was rapidly degraded in the aqueous compartment of small experimental pools incubated in a greenhouse, but was persistent in the sediment compartment.[134] Although these results agreed with previous work with laboratory systems, the concentration of the pesticide in the sediment compartment was much higher than would have been expected from aqueous water solubility and calculated partition coefficients. This pesticide was detected in runoff water entering Lake Kinnert in Israel.[135] The mechanism of interaction of chloridazone, a heterocyclic herbicide, with montmorillonite was studied using x-ray diffraction and I.R. spectroscopy.[136] With methanoic solutions of the herbicide, three stable complexes were formed probably as a result of interactions of the nitrogen atoms in the pyridazone ring and/or the C = O group of the chloridazone molecule. Results from laboratory model ecosystems indicated that atrazine, a widely used, moderately persistent herbicide, was rapidly inactivated by adsorption and/or metabolism in estuarine sediment.[137] Three applications of diflubenzuron, a chitin synthesis inhibitor, to a supratidal mosquito breeding lagoon showed that the pesticide accumulated in sediments and persisted. It slowly disappeared in the water column.[138] The degradation product, 4-chlorophenyl urea, was also detected, but its concentration was oddly unrelated to changes in concentration of the diflubenzuron. A review of degradation studies on diflubenzuron has been published.[139]

Concentrations of chlordane in lake sediments strongly suggest that inputs originated from a contaminated groundwater source.[140] Bioconcentration of the chlordane by sediment-dwelling oligochaetes and the eventual predation of the oligochaetes by fish, possibly explains the route of chlordane contamination in fish samples from the lake. Dicofol or Kelthane,® a pesticide which structurally can be considered as the α-hydroxy analog of DDT, readily photolyzed into various products but not DDE.[141] However, an impurity in the pesticide formulation, α-chlor-DDT, was photolytically converted to DDE. A comparison of the biodegradation rates of the herbicide propanol (3,4-dichlorophenyl propionanilide) in water samples from the USSR and the U. S. showed that differences could be generally normalized to the total number of viable bacteria in the samples.[142] Lag times before the onset of degradation were from 2 to 164 hours and could not be related to cell numbers. The herbicide glyphosate (Roundup®) readily degraded in deionized water when exposed to ultraviolet light.[143] Aminomethyl phosphonic acid was produced as the main degradation intermediate. This product was more susceptible to photolysis than the parent chemical but was resistant to biodegradation. The biodegradation of propanol, a dichloroacylanilide herbicide, in distilled water was the result of a commensal relationship between two bacterial strains that could use the herbicide as a source of carbon, nitrogen and energy.[144] Neither strain alone could degrade the herbicide. Lopez-Avida *et al.*[145] have described an isotope dilution, GC/MS technique for the analysis of low parts per billion concentrations of tritium-labeled dicamba and 2,4-D in water and soil. Using a synthetic laboratory microecosystem designed to model a flooded rice paddy, Isensee and Tayaputch[146] showed that the pesticide was not persistent and caused no toxic effects to fish.

Barbera *et al.*[147] have detected significant concentrations of Dicofol, Fenson and Tetradifon, pesticides with chemical structures similar to DDT, in water samples from the Mediterranean Sea. The photolysis of Folpet, a halo-alkylthioimide fungicide, under UV light resulted in complete dechlorination and the production of phthalimide as the principal product.[148]

HEAVY METALS

Concentrations of heavy metals have been measured in a variety of environmental components including rain water and sediments.[149-156] Silver was associated with sediments receiving acid mine drainage,[151] aluminum concentrations have been monitored in river water,[155] and tri- and dialkyl lead species have been measured in water.[156] Eight heavy metals were in Mississippi River water but at very low concentrations.[157] Thallium moves from water into plants and fish but no transport was seen between sand and other ecosystem components.[158] Beryllium concentrations have been measured in the sediments from Nagoya Harbor Estuary.[159] Although its source, beryllium-smelting plants, has been closed since 1975, the metal accumulated in sediments at the mouth of Nagoya Harbor. Diurnal variations in the chemical environment of a shallow tidal inlet in South Australia, resulting in extreme fluctuations in redox potential, pH, dissolved oxygen, and H_2S concentrations, affected water quality through the release of heavy metal from sediments.[160] Field and laboratory observations demonstrated the dominant influence of solar irradiance on the dynamics of trace metal migration from these sediments. Water residence time, sediment characteristics, and the density of benthic organisms were also of importance in the migration.

Higgo and Rees[161] showed that the decrease in the sediment-water partition coefficient of several actinides with increasing sediment concentration can be frequently explained by a small amount of nonseparable particulate material that has a different partition coefficient than the bulk sediment. These nonseparable particulates may be colloids or stable complexes. Using encirclement correlations of the rates of dissolution of adsorbate and matrix elements to provide insights into the mechanisms of accumulation for such anions as arsenate and phosphate in lake sediments, Agett and Roberts[162] showed that the constancy of the iron:arsenic and iron:phosphate ratio during dissolution is caused by the incorporation of arsenic and phosphorous into sediments by coprecipitation as hydrous oxides. Fish *et al.*[163] compared discrete and continuous multiligand models for metal-humate interactions using both synthetic and experimental data. The discrete ligand approach was the most useful way to model metal-humate binding.

Sediment bacteria are involved in the mobilization of chromium from sediment, and, through adsorption of chromium to the polysaccharide on their surface, the bacteria act as a vehicle by which these metals enter the food chain.[164-165] The binding of chromium to the extracellular polysaccharide may allow the

cells to withstand high concentrations of the metal, a result which corresponds with the higher incidence of mucoid cells in chromium-polluted sediments. Rapin *et al.*[166] have shown that sample pretreatment, such as storage procedures, may affect the partitioning of trace metals to sediments and thereby adversely affect analytical methods. Acceptable preservation techniques were freezing and short-thermal wet storage at 1 to 2°C. A study to quantify the relative significance of mercury inputs from anthropogenic and natural sources to a series of remote lakes in Canada showed that geologic input of mercury was significant in all study lakes. In several areas, however, the presence of mercury concentrations was two to four times higher in surface sediments than in underlying sediments, strongly suggesting anthropogenic inputs from atmospheric deposition. The average anthropogenic component of mercury burdens in all the lakes was 0.79 mg/m^2.[167] High concentration of mercury in sediments and associated plants was attributed to effluents from a caustic-chlorine industrial site.[168] The release of mercury from contaminated sediments, as measured by uptake into killifish, showed that low oxygen conditions gave high concentrations in the fish.[169] Aeration of the sediments by stirring resulted in lower mercury uptake. Mercury concentration in sediment was not related to uptake by the fish. Methylation of mercury in sediment was unusually low in a polluted stream, probably because of its unavailability for microbial attack.[170] A causal connection was established between the high sulfide levels in the stream and the absence of mercury methylation. In anoxic sediments, biochemical processes rather than chemical processes were responsible for most of the observed mercury methylation.[171] Aerobic soils presumably allowed much more biological demethylation of mercury and thus made it more difficult to distinguish between chemical and biological methylation of mercury. Three dissolved methylated selenium compounds have been detected in natural water samples by an in-field cryogenic trapping technique.[172] A pathway involving selenium reduction, formation of selenomethionine by biological methylation, and finally abiotic hydrolysis to dimethyl selenide, has been proposed.

In a very large monitoring program, Maguire *et al.*[173] showed that 10% of the 265 sampling sites in Canada had tributyltin concentrations in the water that would cause toxic effects if laboratory toxicity data were considered. Some sediment samples had high tributyltin concentrations but the bioavailability of the organometallic compound was uncertain. Traces of methyltin were also observed at several sites. High tributyltin and dibutyltin concentrations of marine waters reflect the increased pleasure boat activity and the impact of tributyltin-containing anti-fouling paints.[174] Inorganic tin IV and monobutyl tin were only in trace quantities, suggesting no significant accumulation of degradation products. Laughlin *et al.*[175] showed that different chemical specification products of tributyltin exist in seawater and the equilibrium distribution of these specification products are mediated by anion concentrations. Equilibrium distribution was therefore readily displaced by variations in salinity. Tributyltin biodegraded in seawater to dibutyltin and small amounts of monobutyltin.[176] Half-lives in water collected from a yacht harbor were 6 and 7 days for light and dark treatments, respectively and 9 and 19 days in clean water under similar treatments. Photolysis was not a significant decay process.

P. H. Pritchard is with the U. S. EPA Environmental Research Lab, Sabine Island, Gulf Breeze, FL 32561.

REFERENCES

1. Xie, T., *et al.*, "Distribution of Chlorophenols in a Marine Environment." *Environ. Sci. Technol.*, **20,** 457 (1986).
2. Kuivashniemi, K., *et al.*, "Ageing of Bleached Kraft Mill Effluent Studies by Degradation of Chlorinated Phenolic Compounds and *Selenastrum* Algal Assays." *Environ. Poll. (Series A)*, **41,** 247 (1986).
3. Folke, J., and Birklund, J., "Danish Coastal Water Levels of 2,3,4,6-Tetrachlorophenol, Pentachlorophenol and Total Organohalogens in Blue Mussels (*Mytilus edulis*)." *Chemosphere*, **15,** 895 (1986).
4. Hwang, H., *et al.*, "Degradation of Phenol and Chlorophenol by Sunlight and Microbes in Estuarine Water." *Environ. Sci. Technol.*, **20,** 1002 (1986).
5. Seidler, J. J., *et al.*, "Persistence of Pentachlorophenol in a Wastewater-Estuarine Aquaculture System." *Bull. Environ. Contam. Toxicol.*, **36,** 101 (1986).
6. Krijgsheld, K. R., and Van der Gren, A., "Assessment of the Impact of the Emission of Certain Organochlorine Compounds on the Aquatic Environment Part I: Monochlorophenols and 2,4-Dichlorophenol." *Chemosphere*, **15,** 825 (1986).
7. Krijgsheld, K. R., and Van der Gren, A., "Assessment of the Impact of the Emission of Certain Organochlorine Compounds on the Aquatic Environment Part II: Allychloride, 1,3- and 2,3-dichloropropene." *Chemosphere*, **15,** 861 (1986).
8. Krijgsheld, K. R., and Van der Gren, A., "Assessment of the Impact of the Emission of Certain Organochlorine Compounds on the Aquatic Environment Part IiI: Epichlorohydrin." *Chemosphere*, **15,** 881 (1986).
9. Hutzinger, O., *et al.*, "Chlorinated Dioxins and Related Compounds, 1985." *Chemosphere*, **15,** 1085 (1986).
10. Webster, G. R., *et al.*, "Dissolved Organic Matter Mediated Aquatic Transport of Chlorinated Dioxins." *Chemosphere*, **15,** 1379 (1986).
11. Masse, R., and Pelleatier, B., "Photochemistry of Dibenzo-p-dioxin in Organic Solvents at 253.7 nm: GC/MS Characterization of the Phototransformation Products." *Chemosphere*, **16,** 7 (1987).
12. Podoll, R. T., *et al.*, "Tetrachlorodibenzodioxin: Rates of Volatilization and Photolysis in the Environment." *Environ. Sci. Technol.*, **20,** 490 (1986).
13. Eduljee, G., "Volatility of TCDD and PCB from Soil." *Chemosphere*, **16,** 907 (1987).
14. Marple, L., *et al.*, "Water Solubility of 2,3,7,8-Tetrachloro-dibenzo-*p*-dioxin." *Environ. Sci. Technol.*, **20,** 180 (1986).
15. Marple, L., *et al.*, "Measurement of the Water-Octanol Partition Coefficient of 2,3,7,8-Tetrachlorodibenzo-*p*-dioxin." *Environ. Sci. Technol.*, **20,** 397 (1986).
16. Wu, S., and Gschwend, P. M., "Sorption Kinetics of Hydrophobic Organic Compounds to Natural Sediments and Soils." *Environ. Sci. Technol.*, **20,** 717 (1986).
17. Mackay, D., and Powers, B., "Sorption of Hydrophobic Chemicals from Water: A Hypothesis for the Mechanism of the Particle Concentration Effect." *Chemosphere*, **16,** 745 (1987).
18. de Bont, J. A., *et al.*, "Microbial Degradation of 1,3-Dichlorobenzene." *Appl. Environ. Microbiol.*, **52,** 677 (1986).
19. Bachmann, A., *et al.*, "Biodegradation of Alpha- and Beta-Hexachlorocyclohexane in a Soil Slurry under Different Redox Conditions." *Appl. Environ. Microbial.*, **54,** 143 (1988).
20. Preiss, U., *et al.*, "Degradation of Veratrylglycerol-β-Pentachlorophenyl Ether, a Model Compound for Lignin Bound Pentachlorophenol Residues." *Chemosphere*, **16,** 963 (1987).
21. Zitzelsberger, W., *et al.*, "Sterospecificity of the Degradation of Veratrylglycerol-β-2,4-Dichlorophenylether, Mode Compound for Lignin Bound Xenobiotic Residues by *Phanerochaete chrysosporium, Corynebacterium equi* and Photosensitized Riboflavin." *Chemosphere*, **16,** 1137 (1987).
22. Melcer, M. E., *et al.*, "Evidence for a Charge-Transfer Interaction Between Dissolved Humic Materials and Organic Molecules: I.

Study of the Binding Interaction Between Humic Materials and Chloranil." *Chemosphere*, **16**, 1115 (1987).
23. Chiou, C. T., *et al.*, "A Comparison of Water Solubility Enhancements of Organic Solutes by Aquatic Humic Materials and Commercial Humic Acids." *Environ. Sci. Technol.*, **21**, 1231 (1987).
24. Wilson, B. H., *et al.*, "Biotransformation of Selected Alkylbenzenes and Halogenated Aliphatic Hydrocarbons in Methanogenic Aquifer Material: A Microcosm Study." *Environ. Sci. Technol.*, **20**, 997 (1986).
25. Gibson, S. A., and Suflita, J. M., "Extrapolation of Biodegradation Results to Groundwater Aquifers: Reductive Dehalogenation of Aromatic Compounds." *Appl. Environ. Microbiol.*, **52**, 681 (1986).
26. Vogel, T. M., and Reinhard, M., "Reaction Products and Rates of Disappearance of Simple Bromoalkanes, 1,2-Dibromopropane and 1,3-Dibromoethane in Water." *Environ. Sci. Technol.*, **20**, 992 (1986).
27. Vogel, T. M., *et al.*, "Transformation of Halogenated Aliphatic Compounds." *Environ. Sci. Technol.*, **21**, 722 (1987).
28. Vogel, T. M., and McCarty, P. L. "Abiotic and Biotic Transformations of 1,1,1-Trichloroethane under Methanogenic Conditions." *Environ. Sci. Technol.*, **21**, 1208 (1987).
29. Barrio-Lage, G., *et al.*, "Kinetics of the Depletion of Trichloroethene." *Environ. Sci. Technol.*, **21**, 336 (1987).
30. Cooper, *et al.*, "Abiotic Transformations of Halogenated Organics. 1. Elimination Reaction of 1,1,2,2-Tetrachloroethane and Formation of 1,1,2-Trichloroethene." *Chemosphere*, **11**, 112 (1987).
31. Fathepure, B. Z., *et al.*, "Anaerobic Bacteria that Dechlorinate Perchloroethene." *Appl. Environ. Microbiol.*, **53**, 2671 (1987).
32. Seligman, P. F., Valkirs, A. O., and Lee, R. F., "Degradation of Tributyltin in San Diego Bay, California, Waters." *Environ. Sci. Technol.*, **20**, 1229 (1986).
33. Doucette, W. J., and Andren, A. W., "Correlation of Octanol/water Partition Coefficients and Total Molecular Surface Area for Highly Hydrophobic Aromatic Compounds." *Environ. Sci. Technol.*, **21**, 821 (1987).
34. Villeneuve, J., and Cattini, C., "Input of Chlorinated Hydrocarbons through Dry and Wet Deposition to the Western Mediterranean." *Chemosphere*, **15**, 115 (1986).
35. Winger, P. V., and Anderson, J. K., "Contaminant Residues in Fish and Sediments from Lakes in the Atchafalaya River Basin (Louisiana)." *Arch. Environ. Contam. Toxicol.*, **14**, 579 (1985).
36. Bush, B., *et al.*, "Sedimentation of 74 PCB Congeners in the Upper Hudson River." *Chemosphere*, **16**, 733 (1987).
37. Galassi, S., and Migliavacca, M., "Organochlorine Residues in River Po Sediment: Testing the Equilibrium Condition with Fish." *Ecotoxicol. Environ. Safety*, **12**, 120 (1986).
38. Christensen, E. R., and Lo, C. K., "Polychlorinated Biphenyls in Dated Sediments of Milwaukee Harbor, Wisconsin." *Environ. Poll. (Series B)*, **12**, 217 (1986).
39. Sugiura, K., *et al.*, "Polychlorobiphenyls (PCB's) in Sediments of Tokyo Bay, Japan." *Arch. Environ. Contam. Toxicol.*, **15**, 69 (1986).
40. Smith, J. A., *et al.*, "Trace-Metal and Organochlorine Residues in Sediments of the Upper Rockaway River, New Jersey." *Bull. Environ. Contam. Toxicol.*, **39**, 465 (1987).
41. Sarkar, A., and SenGupta, R., "Chlorinated Pesticide Residues in Sediments from the Arabian Sea Along the Central West Coast of India." *Bull. Environ. Contam. Toxicol.*, **39**, 1049 (1987).
42. Buser, H., and Muller, M. D., "Methylthio Metabolites of Polychlorinated-biphenyls Identified in Sediment Samples from Two Lakes in Switzerland." *Environ. Sci. Technol.*, **20**, 730 (1986).
43. Shiaris, M. P., and Jambard-Sweet, D., "Polycyclic Aromatic Hydrocarbons in Surficial Sediments of Boston Harbour, Massachusetts, USA." *Mar. Poll. Bull.*, **17**, 469 (1986).
44. Ali, M. Y., and Riley, J. P., "Distribution of Halomethanes in the Coastal Waters of Kuwait." *Mar. Poll. Bull.*, **17**, 409 (1986).
45. Fogelquist, E., and Krysell, M., "The Anthropogenic and Biogenic Origin of Low Molecular Weight Halocarbons in a Polluted Fjord, the Idefjorden." *Mar. Poll. Bull.*, **17**, 378 (1986).
46. Green, D. R., *et al.*, "Determination of Chlorinated Hydrocarbons in Coastal Waters Using a Moored *in situ* Sampler and Transplanted Live Mussels." *Mar. Poll. Bull.*, **17**, 324 (1986).
47. Jaffe, R., and Hites, R. A., "Fates of Hazardous Waste Derived Organic Compounds in Lake Ontario." *Environ. Sci. Technol.*, **20**, 267 (1986).
48. Watanabe, I., *et al.*, "Confirmation of the Presence of the Flame Retardant Decabromobiphenyl Ether in River Sediment from Osaka, Japan." *Bull. Environ. Contam. Toxicol.*, **36**, 839 (1986).
49. Watanabe, I., *et al.*, "Hexabromobenzene and Its Debrominated Compounds in River and Estuary Sediment in Japan." *Bull. Environ. Contam. Toxicol.*, **36**, 778 (1986).
50. Ov, L. T., and Street, J. J., "Microbial Enhancement of Hydrazine Degradation in Soil and Water." *Bull. Environ. Contam. Toxicol.*, **39**, 541 (1987).
51. Hites, R. A., and Eisenreich, S. J., "Sources and Fates of Aquatic Pollutants." *Am. Chem. Soc.*, Washington, D. C. (1987).
52. Shalalam, A. M., and Mansour, A. R., "Mixed Culture Biological Activity in Water Containing Low Concentrations of Cyanide, Phenol and BOD." *Environ. Poll. (Series A)*, **39**, 351 (1985).
53. Schmidt, S. K., *et al.*, "Kinetics of *p*-Nitrophenol Mineralization by a *Pseudomonas* sp: Effects of Second Substrates." *Appl. Environ. Microbiol.*, **53**, 2617 (1987).
54. Faust, B. C., and Hoigne, J., "Sensitized Photoxidation of Phenols by Fulvic Acid and in Natural Waters." *Environ. Sci. Technol.*, **21**, 957 (1987).
55. Borlakoglo, J. T., and Kickuth, R., "Chlorination of 4-Hydroxycinnamic Acid and its Toxic Risk as a Naturally Occurring Water Contaminant." *Bull. Environ. Contam. Toxicol.*, **37**, 866 (1986).
56. Bossert, I. D., and Young, L. Y., "Anaerobic Oxidation of *p*-Cresol by a Denitrifying Bacterium." *Appl. Environ. Microbiol.*, **52**, 117 (1986).
57. Swindoll, C. M., *et al.*, "Influence of Inorganic and Organic Nutrients on Aerobic Biodegradation and on the Adaptation Response of Subsurface Microbial Communities." *Appl. Environ. Microbiol.* **54**, 212 (1988).
58. Heiman, A. S., and Cooper, W. T., "Solid-state ^{13}C Nuclear Magnetic Resonance Spectroscopy of Simultaneously Metabolized Acetate and Phenol in a Soil *Pseudomonas* sp." *Appl. Environ. Microbiol.*, **53**, 156 (1987).
59. Krone, C. A., *et al.*, "Nitrogen-Containing Aromatic Compounds in Sediments from a Polluted Harbor in Puget Sound." *Environ. Sci. Technol.*, **20**, 1144 (1986).
60. deMorsier, A., *et al.*, "Biodegradation Tests for Poorly-Soluble Compounds." *Chemosphere*, **16**, 833 (1987).
61. Deshpande, S. D., *et al.*, "Mixed-Substrate Utilization by Acclimated Activated Sludge in Batch and Continuous-Flow Stirred Tank Reactors." *Environ. Sci. Technol.*, **21**, 1003 (1987).
62. Scheunert, I., *et al.*, "Biomineralization Rates of ^{14}C-Labeled Organic Chemicals in Aerobic and Anaerobic Suspended Soil." *Chemosphere*, **16**, 1031 (1987).
63. Vaishnau, D. D., *et al.*, "Quantitative Structure-Biodegradability Relationships for Alcohols, and Alicyclic Compounds." *Chemosphere*, **16**, 695 (1987).
64. Podoll, R. T., *et al.*, "Sorption of Water-Soluble Oligomers on Sediments." *Environ. Sci. Technol.*, **21**, 562 (1987).
65. Mitchell, W. R., "Microbial Degradation of Guanidinium Ion." *Chemosphere*, **16**, 1071 (1987).
66. Hudson-Baruth, B. A., and Seitz, M. G., "Adsorption of Select Phenol Derivatives by Dolomite." *Environ. Poll. (Series B)*, **11**, 15 (1986).
67. Smith, A., and Colquhoun, K. O., "Biodegradability of Hexamethylenetramine." *Chemosphere*, **16**, 1555 (1987).
68. Dorn, P. B., *et al.*, "Degradation of Bisphenol A in Natural Waters." *Chemosphere*, **16**, 1501 (1987).

69. Steber, J., and Wierich, P., "Properties of Aminotris (Methylene Phosphonate) Affecting its Environmental Fate: Degradability, Sludge Adsorption, Mobility in Soils and Bioconcentration." *Chemosphere*, **16,** 1323 (1987).
70. Suzuki, J., *et al.*, "Photochemical Reaction of Biphenyl in Water Containing Nitrite and Nitrate Ion." *Chemosphere*, **16,** 1289 (1987).
71. Parsons, J. R., "Influence of Membrane Permeation on Biodegradation Kinetics of Hydrophobic Compounds." *Chemosphere*, **16,** 1361 (1987).
72. Brodsky, J., *et al.*, "Chemical Degradation of Xenobiotics. II. Simulation of the Biotic Transformation of Biz(z-ethylhexyl) Phthalate and Dioctylphthalate by Abiotic Means." *Chemosphere*, **15,** 139 (1986).
73. Anderson, J. T., *et al.*, "Chemical Degradation of Xenobiotics. III. Simulation of the Biotic Transformation of 2-Nitrophenol and 3-Nitrophenol." *Chemosphere*, **15,** 149 (1986).
74. Thuren, A., "Determination of Phthalates in Aquatic Environments." *Bull. Environ. Contam. Toxicol.*, **36,** 33 (1986).
75. Russell, D. J., *et al.*, "The Effect of Biodegradation on the Determination of some Chemodynamic Properties of Phthalate Esters." *J. Environ. Sci. Health*, **A20,** 927 (1985).
76. Hales, S. G., *et al.*, "A Comparative Study of the Biodegradation of the Surfactant Sodium Dodecyltriethoxy Sulfate by Four Detergent-degrading Bacteria." *J. Gen. Microbiol.*, **132,** 953 (1986).
77. Griffiths, E. T., *et al.*, "Metabolite Production during the Biodegradation of the Surfactant Sodium Dodecyltriethoxy Sulfate under Mixed-Culture Die-Away Conditions." *J. Gen. Microbiol.*, **132,** 963 (1986).
78. Sales, D., *et al.*, "Primary Biodegradation Kinetics of Anionic Surfactants in Marine Environment." *Bull. Environ. Contam. Toxicol.*, **39,** 385 (1987).
79. Gard-Terech, A., and Palla, J. C., "Comparative Kinetics Study of the Evolution of Freshwater Toxicity and Biodegradability of Linear and Branched Alkylbenzene Sulfonates." *Ecotoxicol. Environ. Safety*, **12,** 127 (1986).
80. Ward, T. E., "Aerobic and Anaerobic Biodegradation of Nitrilotriacetate in Subsurface soils." *Ecotoxicol. Environ. Safety*, **11,** 112 (1986).
81. Larson, R. J., and Ventullo, R. M., "Kinetics of Biodegradation of Nitrilotriacetic Acid (NTA) in an Estuarine Environment." *Ecotoxicol. Environ. Safety*, **12,** 166 (1986).
82. Steber, J., and Wierich, P., "Properties of Hydroxyethane Diphosphonate Affecting Its Environmental Fate: Degradability, Sludge Adsorption, Mobility in Soils and Bioconcentration." *Chemosphere*, **15,** 929 (1986).
83. Holysh, M., *et al.*, "Assessment of the Environmental Fate of Linear Alkylbenzenesulphonates." *Chemosphere*, **15,** 3 (1986).
84. Mackay, D., *et al.*, "A Quantitative Water, Air, Sediment Interaction (QWASI) Fugacity Model for Describing the Fate of Chemicals in Rivers." *Chemosphere*, **12,** 1193 (1983).
85. Simkins, S., *et al.*, "Two Approaches to Mocking Kinetics of Biodegradation by Growing Cells and Application of a Two-Compartment Model for Mineralization Kinetics in Sewage." *Appl. Environ. Microbiol.*, **51,** 1153 (1986).
86. Rubio, M. A., *et al.*, "Microbial Metabolism of Chlorosalicylates; Accelerated Evolution by Natural Genetic Exchange." *Arch. Microbiol.*, **145,** 116 (1986).
87. Tschech, A., and Schink, B., "Fermentative Degradation of Monohydroxy Benzonates by Defined Syntrophic Cocultures." *Arch. Microbiol.*, **145,** 396 (1986).
88. Painter, H. A., and King, E. F., "The Need for Applying Stability Tests in Biodegradability Assessments." *Chemosphere*, **15,** 471 (1986).
89. Bartlett, P. D., "Degradation of Coprostanol in an Experimental System." *Mar. Poll. Bull.*, **18,** 27 (1986).
90. Ho, P. C., "Photooxidation of 2,4-Dinitrophenol in Aqueous Solution in the Presence of Hydrogen Peroxide." *Environ. Sci. Technol.*, **20,** 260 (1986).
91. Pagga, V., and Brown, D., "The Degradation of Dyestuff; Part II, Behavior of Dyestuffs in Aerobic Biodegradation Tests." *Chemosphere*, **15,** 479 (1986).
92. Nortemann, B., *et al.*, "Bacterial Communities Degrading Amino- and Hydroxynaphthalene-2-Sulfonates." *Appl. Environ. Microbiol.*, **52,** 1195 (1986).
93. Brown, D., and Hamburger, B., "The Degradation of Dyestuffs: Part III - Investigations of Their Ultimate Degradability." *Chemosphere*, **16,** 1539 (1987).
94. de Morsier, A., "Environmental Aspects of Polymer Additives." *Ecotoxicol. Environ. Safety*, **10,** 184 (1985).
95. Lytle, T. F., and Lytle, J. S., "Lignin Residues as Tracers of Organic Waste Transport." *Chemosphere*, **16,** 171 (1987).
96. Edgerton, *et al.*, "Hydrocarbon Fuel Spill Dispersion on Water: A Literature Review." *Chemosphere*, **16,** 1475 (1987).
97. Killops, S. D., "Identification of Petrogenic Contamination in Recent Sediments by HPLC Monitoring of Aromatic Components: A Preliminary Investigation." *Chemosphere*, **15,** 229 (1986).
98. Strain, P. M., "The Persistence and Mobility of a Light Crude Oil in a Sandy Beach." *Mar. Environ. Res.*, **19,** 49 (1986).
99. Fayad, N. M., "Identification of Tar Balls Following the Nowruz Oil Spill." *Mar. Environ. Res.*, **18,** 155 (1986).
100. Urdal, K., *et al.*, "Classification of Weathered Crude Oils Using Multimethod Chemical Analysis, Statistical Methods and SIMPC Pattern Recognition." *Mar. Poll. Bull.*, **17,** 366 (1986).
101. Knap, A. H., *et al.*, "Dissolved/dispersed Hydrocarbons, Tarballs and Surface Microlayer: Experiences from an IOC/UNEP Workshop in Bermuda, December, 1984." *Mar. Poll. Bull.*, **17,** 313 (1986).
102. Burris, D. R., and MacIntyre, W. G., "Solution of Hydrocarbons in a Hydrocarbon-Water System with Changing Phase Composition due to Evaporation." *Environ. Sci. Technol.*, **20,** 296 (1986).
103. Takoda, H., and Ishiwatari, R., "Linear Alkylbenzenes in Urban Riverine Environments in Tokyo; Distribution, Source, and Behavior." *Environ. Sci. Technol.*, **21,** 875 (1987).
104. Bayonna, J. M., *et al.*, "Selective Aerobic Degradation of Linear Aklylbenzenes by Pure Microbial Cultures." *Chemosphere*, **15,** 595 (1986).
105. Blackburn, J. W., *et al.*, "Molecular Microbial Ecology of a Naphthalene-degrading Genotype in Activated Sludge." *Environ. Sci. Technol.*, **21,** 884 (1987).
106. Trower, M. K., *et al.*, "Isolation and Characterization of a Cyclohexane-metabolizing *Xanthobacter* sp." *Appl. Environ. Microbiol.*, **49,** 1282 (1985).
107. Magor, A. M., *et al.*, "Comparative Study of the Ability of three *Xanthobacter* Species to Metabolize Cyclohexanes." *Appl. Environ. Microbiol.*, **52,** 665 (1986).
108. Wakehan, S. G., *et al.*, "Behavior of Aliphatic Hydrocarbons in Coastal Seawater: Mecocosm Experiments with [^{14}C] Octadecane and [^{14}C] Decane." *Environ. Sci. Technol.*, **20,** 574 (1986).
109. Latimer, J. S., *et al.*, "Treatment of Solids and Petroleum Hydrocarbons in Storm Runoff with an On-Site Detention Basin." *Bull. Environ. Contam. Toxicol.*, **36,** 548 (1986).
110. Mantel, L., *et al.*, "Polycyclic Aromatic Hydrocarbons in Sediments from Sequenay Fjord, Canada." *Bull. Environ. Contam. Toxicol.*, **37,** 133 (1986).
111. Shiaris, M. P., and Jambard-Sweet, D., "Polycyclic Aromatic Hydrocarbons in Surficial Sediments of Boston Harbour, Massachusetts, USA." *Mar. Poll. Bull.*, **17,** 469 (1986).
112. Larsen, P. F., *et al.*, "Polycyclic Aromatic Hydrocarbons in Gulf of Marine Sediments; Distribution and Mode of Transport." *Mar. Environ. Res.*, **18,** 231 (1986).
113. West, W. R., *et al.*, "Determination of Genotoxic Polycyclic Aromatic Hydrocarbons in a Sediment from the Black River (Ohio)." *Arch. Environ. Contam. Toxicol.*, **15,** 241 (1986).
114. Readman, J. W., *et al.*, "An Integrated Technique to Quantify Sewage, Oil and PAH Pollution in Estuarine and Coastal Environments." *Mar. Poll. Bull.*, **17,** 289 (1986).

115. Vowles, P. D., and Montoura, R. F., "Sediment-Water Partition Coefficients and HPLC Retention Factors of Aromatic Hydrocarbons." *Chemosphere*, **16**, 109 (1987).
116. Gauthier, T. D., *et al.*, "Fluorescence Quenching Method for Determining Equilibrium Constants for Polycyclic Aromatic Hydrocarbons Binding to Dissolved Humic Materials." *Environ. Sci. Technol.*, **20**, 1162 (1986).
117. Morehead, N. R., *et al.*, "The Sorption of PAH onto Dissolved Organic Matter in Lake Michigan Waters." *Chemosphere*, **15**, 403 (1986).
118. Chiou, C. T., *et al.*, "Water solubility enhancement of some organic pollutants and pesticides by dissolved humic and fulvic acid." *Environ. Sci. Technol.*, **20**, 502 (1986).
119. Hinga, K. R., *et al.*, "The Degradation of 7, 12-Dimethylbenz(a)anthracene in an Enclosed Marine Ecosystem." *Mar. Environ. Res.*, **18**, 79 (1986).
120. Suzuki, J., *et al.*, "Formation of 1-Nitropyrene by Photolysis of Pyrene in Water Containing Nitrite Ion." *Chemosphere*, **16**, 859 (1987).
121. Novick, N. J., *et al.*, "Metabolism of Alachlor and Propachlor in Suspensions of Pretreated Soils and in Samples from Ground Water Aquifer." *J. Agric. Food Chem.*, **34**, 721 (1986).
122. Novick, N. J., and Alexander, M., "Mineralization of Alachlor and Propachlor by Microbial Communities in Lake Water and Sewage." *Appl. Environ. Microbiol.*, **49**, 737 (1985).
123. Francies, B. M., *et al.*, "Model Ecosystem Studies of the Environmental Fate of Five Herbicides Used in Conservation Tillage." *Arch. Environ. Contam. Toxicol.*, **14**, 693 (1985).
124. Foran, J. A., *et al.*, "Temik Contamination in a Surface Water System and It's Potential Effect on a Daphnid species in Florida." *Environ. Poll.*, (*Series A*), **40**, 369 (1986).
125. Albanis, T. A., *et al.*, "Organophosphorous Carbamate Pesticide Residues in the Aquatic System of Ioannia Basin and Kalamas River (Greece)." *Chemosphere*, **15**, 1023 (1986).
126. Pritchard, P. H., *et al.*, "Biotic and Abiotic Degradation Rates of Methyl Parathion in Freshwater and Estuarine Water And Sediment Samples." *Chemosphere*, **16**, 1509 (1987).
127. Abdov, W. M., *et al.*, "Photochemistry of Pesticides, 6. Comparative Photochemical Studies on Methyl-2-benzimidazole Carbamate (carbendazim) and Methyl (1-n-butylcarbomyl)-2-benzimidasolecarbamate (Benlate) in Aqueous Hydrochloric Acid." *Chemosphere*, **15**, 1063 (1986).
128. Rajagopal, B. S., *et al.*, "Accelerated Degradation of Carbanyl and Carbofuran in a Flooded Soil Pretreated with Hydrolysis Products, 1-Napthol and Carbofuran Phenol." *Bull. Environ. Contam. Toxicol.*, **36**, 299 (1986).
129. Fisher, S. W., and Lohner, T. W., "Studies on the Environmental Fate of Carbanyl as a Function of pH." *Arch. Environ. Contam. Toxicol.*, **15**, 661 (1986).
130. Sabharwal, A. K., and Belsare, D. K., "Persistence of Methyl Parathion in a Carp Pond." *Bull. Environ. Contam. Toxicol.*, **37**, 705 (1986).
131. Fisher, S. W., "Effects of pH upon the Environmental Fate of [^{14}C] Fenitrothion in an Aquatic Microcosm." *Ecotoxicol. Environ. Safety*, **10**, 53 (1985).
132. Suorsa, K. E., and Fisher, S. W., "Effects of pH on the Environmental Fate of [^{14}C] Aldicarb in an Aquatic Microcosm." *Ecotoxicol. Environ. Safety*, **11**, 81 (1986).
133. Kearney, P. C., *et al.*, "Compound Disposal by Combined Microbial and UV-Ozonation Reactions." *J. Agr. Food Chem.*, **34**, 702 (1986).
134. Reinert, K. H., *et al.*, "Compartmentalization and Persistence of Endothall in Experimental Ponds." *Ecotoxicol. Environ. Safety*, **10**, 86 (1985).
135. Wynne, D., "The Potential Impact of Pesticides on the Kinneret and Its Watershed." *Environ. Poll.* (*Series A*), **42**, 373 (1986).
136. Sanchez-Martin, M. J., and Sanchez-Camazano, "Adsorption of Chloridazone by Montmorillonite." *Chemosphere*, **16**, 937 (1987).
137. Isensee, A. R., "Persistence and Movement of Atrazine in a Saltmarsh Sediment Microecosystem." *Bull. Environ. Contam. Toxicol.*, **39**, 516 (1987).
138. Cunningham, P. A., and Myers, L. E., "Dynamics of Diflubenzuron (Dimilin®) Concentrations in Water and Sediment of a Supertidal Saltmarsh Site Following Repetitive Aerial Applications for Mosquito Control." *Environ. Poll.* (*Series A*), **41**, 63 (1986).
139. Cunningham, P. A., "A Review of Toxicity Testing and Degradation Studies Used to Predict the Effects of Diflubenzuron (Dimilin®) on Estuarine Crustaceans." *Environ. Poll.* (*Series A*), **40**, 63 (1986).
140. Wood, L. W., *et al.*, "Possible Sediment Scavenging of Chlordane and Contamination of the Aquatic Biota in Belmont Lake, New York." *Bull. Environ. Contam. Toxicol.*, **36**, 159 (1986).
141. Ruzo, L. O., and Casida, J. E., "Photochemical Conversion of a Dicofol Impurity, α-Chloro-DDT, to DDE." *Bull. Environ. Contam. Toxicol.*, **37**, 791 (1986).
142. Steen, W. C., *et al.*, "Microbial Degradation of Propanol in Aquatic Systems." *Chemosphere*, **15**, 917 (1986).
143. Lund-Hoie, K., and Friestad, H. O., "Photodegradation of the Herbicide Glyphosate in Water." *Bull. Environ. Contam. Toxicol.*, **36**, 723 (1986).
144. Danchour, A., *et al.*, "Degradation of the Herbicide Propanol in Distilled H_2O." *Bull. Environ. Contam. Toxicol.*, **36**, 556 (1986).
145. Lopez-Avila, V., *et al.*, "Determination of Dicarba and 2,4-D in Water and Soil by Isotope Dilution GC/MS." *J. Agric. Food Chem.*, **34**, 530 (1986).
146. Isensee, A. R., and Tayaputch, N., "Distribution of Carbonfuran in a Rice-Paddy Fish Microecosystem." *Bull. Environ. Contam. Toxicol.*, **36**, 763 (1986).
147. Barbera, J. C., *et al.*, "Gas Chromatographic Determination of Organochlorine Pesticides; Contamination of Dicofol, Fenson and Tetradifon in Fish and Natural Waters of a Wet Area Beside the Mediterranean Sea." *Bull. Environ. Contam. Toxicol.*, **36**, 211 (1986).
148. Schwack, W., "N-(Dichloromethylthio)-phthalimine, a Photometabolite of Folpet." *Chemosphere*, **16**, 127 (1987).
149. Byrne, C. J., and Deleon, I. R., "Trace Metal Residues in Biota and Sediments from Lake Pontchartrain, Louisiana." *Bull. Environ. Contam. Toxicol.*, **37**, 151 (1986).
150. Aten, C. F., *et al.*, "Heavy Metal Content of Rainwater in Geneva, New York During 1983." *Bull. Environ. Contam. Toxicol.*, **36**, 918 (1986).
151. Jones, K. C., "The Distribution and Partitioning of Silver and Other Heavy Metals in Sediments Associated with an Acid Mine Drainage Stream." *Environ. Poll.* (*Series B*), **12**, 249 (1986).
152. Modamio, X., "Heavy Metal Distribution on the Coast of Catalonia." *Mar. Poll. Bull.*, **17**, 383 (1986).
153. White, D. H., *et al.*, "Trace Elements in Sediments, Water, and American Coots (*Fulica americana*) at a Coal-fixed Power Plant in Texas, 1979–1982." *Bull. Environ. Contam. Toxicol.*, **36**, 376 (1986).
154. Thompson, B. E., *et al.*, "Contaminants in Sediments of Two Nearshore Basin Slopes off Southern California." *Mar. Poll. Bull.*, **17**, 404 (1986).
155. Bull, K. R., and Hall, J. R., "Aluminium in the Rivers Esk and Duddon, Cumbria, and Their Tributaries." *Environ. Poll.* (*Series B*), **12**, 165 (1986).
156. Purchase, N. G., and Fergussion, J. E., "The Distribution and Geochemistry of Lead in River Sediments, Christ Church, New Zealand." *Environ. Poll.* (*Series B*), **12**, 203 (1986).
157. DeLeon, I. R., *et al.*, "Trace Organic and Heavy Metal Pollutants in the Mississippi River." *Chemosphere*, **15**, 795 (1986).
158. Wallwork-Barber, M. K., *et al.*, "Thallim Movement in a Simply Aquatic Ecosystem." *J. Environ. Sci. Health*, **A20**, 689 (1985).
159. Itoh, K., "Beryllium in Sediments of Nagoya Harbor Estuaries." *Bull. Environ. Contam. Toxicol.*, **36**, 935 (1986).
160. Harbison, P., "Diurnal Variations in the Chemical Environment

of a Shallow Tidal Inlet, Gulf St. Vincent, South Australia; Implications for Water Quality and Trace Metal Migration." *Mar. Environ. Res.*, **20,** 161 (1986).
161. Higgo, J. J., and Rees, L. V., "Adsorption of Actinides by Marine Sediments: Effect of the Sediment/Seawater Ratio on the Measured Distribution Ratio." *Environ. Sci. Technol.*, **20,** 483 (1986).
162. Aggett, J., and Roberts, L. S., "Insight into the Mechanism of Accumulation of Arsenate and Phosphate in Hydro Lake Sediments by Measuring the Rate of Dissolution with Ethylene Diamine Tetraacetic Acid." *Environ. Sci. Technol.*, **20,** 183 (1986).
163. Fish, W., *et al.*, "Metal-Humate Interactions. 2. Application and Comparison of Models." *Environ. Sci. Technol.*, **20,** 676 (1986).
164. Aislabie, J., and Loutit, M. W., "Accumulation of Cr (III) by Bacteria Isolated from Polluted Sediment." *Mar. Environ. Res.*, **20,** 221 (1986).
165. Bremer, P. J., and Loutit, M. W., "Bacterial Polysaccharide as a Vehicle for Entry of Cr (III) to a Food Chain." *Mar. Environ. Res.*, **20,** 235 (1986).
166. Rapin, F., *et al.*, "Potential Artifacts in the Determination of Metal Partitioning in Sediments by a Sequential Extraction Procedure." *Environ. Sci. Technol.*, **20,** 836 (1986).
167. Evans, R. D., "Sources of Mercury Contamination in the Sediments of Small Headwater Lakes in South-Central Ontario, Canada." *Arch. Environ. Contam. Toxicol.*, **15,** 505 (1986).
168. Shaw, B. P., *et al.*, "Mercury in Plants, Soil, and Water from a Caustic Chlorine Industry." *Bull. Environ. Contam. Toxicol.*, **36,** 299 (1986).
169. Weis, P., *et al.*, "Effects of Environmental Factors on Release of Mercury from Berry's Creek (New Jersey) Sediments and Its Uptake by Killifish *Fundulus heteroclitus*." *Environ. Poll.* (*Series A*) **40,** 303 (1986).
170. Berman, M., and Bartha, R., "Control of the Methylation Process in a Mercury-Polluted Aquatic Sediment." *Environ. Poll.* (*Series B*), **11,** 41 (1986).
171. Berman, M., and Bartha, R., "Levels of Chemical Versus Biological Methylation of Mercury in Sediments." *Bull. Environ. Contam. Toxicol.*, **36,** 401 (1986).
172. Cooke, T. D., and Burland, K. W., "Aquatic Chemistry of Selenium: Evidence of Biomethylation." *Environ. Sci. Technol.*, **21,** 1214 (1987).
173. Maguire, R. J., *et al.*, "Occurrence of Organotin Compounds in Water and Sediment in Canada." *Chemosphere*, **15,** 253 (1986).
174. Valkirs, A. O., *et al.*, "Measurement of Butyltin Compounds in San Diego Bay." *Mar. Poll. Bull.*, **17,** 319 (1986).
175. Laughlin, R. B., *et al.*, "Tributyltin in Seawater: Speciation and Octanol-Water Partition Coefficients." *Environ. Sci. Technol.*, **20,** 201 (1986).
176. Baker, J. E., *et al.*, "Influence of Colloids on Sediment-Water Partition Coefficients of Polychlorobiphenyl Congeners in Natural Water." *Environ. Sci. Technol.*, **20,** 1136 (1986).

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This article documents research that was conducted under the auspices of the U.S. Environmental Protection Agency (USEPA). As an arm of the government, the USEPA has a paid up, non-exclusive, irrevocable, worldwide license to reproduce, prepare derivative works, and distribute to the public all of the material contained herein, and to grant others acting on its behalf the right to do so. The USEPA grants to the National Technical Information Service, Department of Commerce, the right to act as its agent in the distribution of this material.